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RESEARCH ARTICLE

THE UTILIZATION OF RED MUD AS A PLANT GROWING MEDIUM WITH THE ADDITION OF ULTISOL SOIL MATERIAL AND COMPOST

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ABSTRACT

The utilization of red mud, which is a residue from the extraction of aluminum from mined bauxite ore, as a plant growing medium, needs to be studied further. There are some chemical aspects that may hinder the growth of, or even cause mortality in, plants such as very high pH, electrical conductivity (EC) and exchangeable Na (Na_{exch}), and very low nutrient elements content. The objective of this study was to investigate the effects of adding Ultisol soil material, mixed with compost, both soil ameliorating agents, to red mud for use as a growing medium for Sengon (*Paraserianthes falcataria*) seedlings. This study was conducted in two stages, namely: washing of the red mud, and trial planting in the greenhouse using different combinations of the soil ameliorants. Washing of the red mud with tap water was intended to reduce the levels of Na, EC, and pH. Trial planting in the greenhouse was carried out in 2-factorial Completely Randomized Design (CRD). Factor 1 was the proportion of the mixture of Ultisol soil material (sm-Ultisol) and red mud, *viz*: (1) 1500 g red mud + 0 g sm-Ultisol, (2) 1000 g red mud + 500 g sm-Ultisol, and (3) 750 g red mud + 750 g sm-Ultisol. Factor 2 was the dosage of compost that was mixed with the red mud and sm-Ultisol, namely: 0, 58.6, and 117.2 g/polybag which corresponded to 0, 2.5 and 5 kg/planting hole, respectively. The results of the trial indicated that washing the red mud could reduce the level of EC from 28.70 dS m^{-1} to 2.68 dS m^{-1}; but it reduced pH and Na_{exch} only from 11.91 and 149.38 $cmol^{(+)}kg^{-1}$ to become 10.55, and 66.74 $cmol^{(+)}$ kg^{-1}, respectively. A better outcome was obtained after the red mud was washed and then, mixed with sm-Ultisol up to 1:1 proportion in which resulted in lower rates of pH, EC, and Na_{exch} from 10.28, 2.53 dS m^{-1} and 62.79 $cmol^{(+)}$ kg^{-1} to 8.65, 2.07 dS m^{-1} and 45.01 $cmol^{(+)}$ kg^{-1}, respectively. The treatment of using a mixture of 750 g red mud + 750 g sm-Ultisol, and adding compost at 117.18 g/polybag gave the best result in improving the chemical property of the red mud growing medium, and producing the best plant growth among all treatment combinations.

Keywords: bauxite, red mud, revegetation, sengon (*Paraserianthes falcataria*), Ultisol

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INTRODUCTION

In processing bauxite to obtain aluminum through Bayer's method, sodium hydroxide is used at high temperature and pressure (Jones, Haynes, & Phillips, 2011). The process yields a residue which is known as red mud. According to Liu, Lin, & Wu (2007), red mud can be characterized by the following chemical properties, namely: pH 11.58,

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EC 28.4 dS m^{-1}, cation exchange capacity (CEC) 883.6 $mmol^{(+)}$ kg^{-1}, and exchangeable cations K_{exch} 70.2 $mmol^{(+)}$ kg^{-1}, Na_{exch} 346.6 $mmol^{(+)}$ kg^{-1}, Mg_{exch} 2.3 $mmol^{(+)}$ kg^{-1}, and Ca_{exch} 464.5 $mmol^{(+)}$ kg^{-1}. Some of these chemical properties render red mud too harsh and unsuitable as a plant growing medium, so it just accumulates in deposition ponds and landfills. At the same time, red mud shows tremendous potential for use as a plant growing medium, thereby, transforming it from an undesirable waste into a useful material. Therefore, in order to utilize the red mud as a medium to promote plant growth, especially for the purpose of revegetating ex-mining sites, the chemical and physical characteristics of red mud need to be studied. To elaborate the high pH, EC and exchangeable cations, particularly Na_{exch}, makes red mud quite unsuitable for plant growth. Thus, red mud needs to be washed first in order to lower its pH value, EC, and level of Na_{exch}. Furthermore, red mud possesses a drawback in that it contains very low amounts of available-P, organic-C, and total-N. Thus, red mud needs to be amended in order to improve its chemical qualities and make it conducive to plant growth. Some research has already been undertaken in this respect, for example, J.W.C. Wong & Ho (1993) found that the addition of gypsum residue to serve as an ameliorating agent, can reduce the levels of pH, EC, Na, and at the same time, increase the availability of Ca in the red mud. In another study, Lubis (2015), reported that the application of bed coal ash and humic substances can increase available-P, Ca_{exch}, Mg_{exch} and CEC of red mud.

The results of the above studies clearly imply that there is a way of making red mud suitable for use as a plant growth medium and that is carrying out some intervention treatments. Besides gypsum, bed coal ash, and humic substances, there are many other materials that can be utilized to improve red mud quality. One alternative additive that can ameliorate the condition of red mud is soil material, and one potential type of soil is Ultisol, which is, coincidentally, found in the vicinity of bauxite mines. Ultisol soil material is highly acidic (Li, Wang, Xu, & Tiwari, 2010), and with very low EC and Na_{exch} rate (Fernandes, Bernoux, Cerri, Feigl, & Piccolo, 2002; Hassan, David, & Abbas, 2014); these are the exact opposite traits of red mud (alkali pH, very high EC and Na_{exch}) (Chen, Phillips, Wei, & Xu, 2010; R. G. Courtney & Timpson, 2005; Xue et al., 2016). Obviously then, the addition of Ultisol soil material can neutralize pH, and lower EC and Na_{exch} of red mud.

Further, another ameliorant that can be effectively applied to improve red mud quality is compost, as it possesses desirable properties including being rich in nutrient elements, and able to increase CEC, improve water-holding capacity, encourage biological activity, and promote granulation of red mud. In this light, the beneficial effects of compost, in combination with Ultisol soil material, on red mud merits investigation.

Based on the foregoing discussion, the objective of this study was to analyze the use of red mud as a plant growing medium, amended through the addition of Ultisol soil material mixed with compost, and using seedlings of *Paraserianthes falcataria* as test plants.

MATERIALS AND METHODS

Materials

Red mud to be tested as a plant growing medium came from the residue of extracting chemical grade aluminum from bauxite ore by means of Bayer's method, at PT Indonesia Chemical Alumina, which is located in Tayan Hilir Sub-Regency, Sanggau Regency, West Kalimantan.

Table1. Characteristics of Ultisol soil material and compost that were added to the red mud

Parameter	Unit	sm-Ultisol	Compost
Physical Properties			
Texture			
Sand	%	7.73	nm
Silt	%	10.85	nm
Clay	%	81.41	nm
Chemical Properties			
pH	-	4.11	6.12
EC	dS m^{-1}	0.06	11.47
N-total	%	0.29	1.99
C-organic	%	2.64	28.69
P-available	ppm P_2O_5	7.20	tr
P-total	% P_2O_5	0.022	0.760
Ca_{exch}	$cmol^{(+)}kg^{-1}$	3.04	64.84
Mg_{exch}	$cmol^{(+)}kg^{-1}$	1.98	3.81
K_{exch}	$cmol^{(+)}kg^{-1}$	0.28	57.16
Na_{exch}	$cmol^{(+)}kg^{-1}$	0.33	45.75
CEC	$cmol^{(+)}kg^{-1}$	39.33	67.49

nm = not measured; tr = trace

Soil material was collected from the topsoil of an Ultisol at Setu Village, Jasinga Sub-Regency, Bogor Regency, West Java, and for compost, cattle dung was used. The characteristics of Ultisol soil material (sm-Ultisol) and compost are summarized in Table 1.

Washing of Red Mud

Before use for greenhouse trial planting, the red mud was washed with tap water in order to reduce excessive Na and bring down EC and pH. In washing, a sample of 10 kg red mud was placed inside a bucket, and 50 liters of tap water was poured into it. Then, the red mud sample was uniformly stirred by manual means to hasten the dissolution of Na, after which the red mud was left to settle for some time, and the dirty water was discarded. This washing cycle - water pouring, stirring, and settling down - was repeated 5 times, and at each time, pH and EC were measured.

The analysis of the chemical parameters of the red mud before and after washing followed the general standard procedure for soil characterization. Measurement of the chemical parameters of red mud includes pH H_2O and EC those were measured using pH- and EC-meters, respectively, organic-C with Walkley & Black method, total-N with Kjeldahl method, available-P with Olsen method, CEC with NH_4OAc 1 N extraction, and exchangeable cations (K_{exch}, Na_{exch}, Mg_{exch} and Ca_{exch}) with NH_4OAc 1 N extraction and measured using a Flame photometer for K_{exch}, Na_{exch} and an Atomic Absorption Spectrophotometer for Mg_{exch} and Ca_{exch}. The texture was determined using pipette method based on Stokes' law.

Trial Planting of Sengon Seedlings

As described earlier, trial planting of sengon seedlings in the greenhouse was conducted with the aim of establishing the utilization potential of red mud, combined with sm-Ultisol and compost, as a plant growing medium. Ultisol soil material was added at a ratio of 0, 0.5, and 1 with red mud volume, while the amount of compost that was mixed along followed dosage levels per 40 x 40 x 40 cm planting hole, which are typically applied in the revegetation of ex-mining lands, namely: 0, 2.5, dan 5 kg/planting hole. For this study, a factorial completely randomized design (CRD) with two factors was used. Factor 1 was the proportion of red mud mixture with sm-Ultisol, consisting of three levels, namely: (P0) = 1500 g red mud + 0 g sm-Ultisol, (P1) = 1000 g red mud + 500 g sm-Ultisol, and (P2) = 750 g red mud + 750 g sm-Ultisol. Factor 2 was dosage of compost, also at three rates, namely: (C0) = 0 g/polybag, (C1) = 58.6 g/polybag, and (C2) = 117.2 g/polybag, which would correspond to 0, 2.5, and 5 kg/planting hole in the plantation, respectively. Each of the (3 x 3)= 9 treatments were replicated three times hence, the total number of sampling units were 27. Aside from the above-mentioned treatments, sengon seedlings were trial-planted for comparison using commonly used potting media, which is made up of a mixture of soil, compost, and husk charcoal.

The washed red mud was then air-dried, sifted with 5 mm sieve, and the fines that passed through the sieve was weighed following the dosage with 105 ^{o}C dry weight base then, homogenized with sm-Ultisol and compost mixture, along with basic fertilizer (NPK Phonska 2.34 g/1.5 kg growing medium). The mixtures were then placed inside polybags and stored for 7 days with water content maintained at field capacity, and then, ± 3-month old seedlings (height ± 35 cm) of sengon were planted, one seedling into each polybag. The day of planting the sengon seedlings into polybag was reckoned as the starting day of the planting experiment.

Weekly observations were undertaken over a period of 12 weeks after planting (WAP), including measurement of height and stem diameter of the growing sengon plants. The experimental plants were harvested after 12 WAP, and destructive plant sampling was done. Plant weight and root length were measured, and samples of the growing media and leaf were collected for chemical analysis.

Post-harvest chemical analysis of the growing media was carried out in the same way as that of the red mud samples, as described earlier. The levels of the nutrient elements (N, P, K, Ca, Mg, Fe, Mn, Cu, and Zn) in the leaf samples were analyzed using wet combustion method with H_2SO_4 and H_2O_2. Cations were determined using Atomic Absorption Spectrophotometer, P was measured with Spectrophotometer, while N was measured using the Kjeldahl method.

The measurement data of plant parameters and chemical analyses were subjected to statistical analysis using Analysis of Variance (ANOVA) at a level of significance of α = 0.05, and for observed treatment differences, further statistical significance test, using Duncan's Multiple Range Test (DMRT) was applied.

RESULTS AND DISCUSSION

Characteristics of Red Mud Before and After Washing

Table 2 shows that pre-washed red mud had a particle size distribution of 27.8% sand, 51.5 % silt, and 20.7% clay. Based on the standard criteria for soil texture class determination, such particle size distribution is of silty loam class. Chemically, the pre-washed and very high EC value (28.70 dS m^{-1}) and Na rate (149.38 $cmol^{(+)}$ kg^{-1}).

Table 2. Characteristics of red mud before and after washing treatment

Parameter	Unit	Before Washing		After Washing	
		Value	Category*	Value	Category*
Physical Properties					
Texture			Silty Loam		Clay
Sand	%	27.8		31.2	
Silt	%	51.5		20.2	
Clay	%	20.7		48.6	
Chemical Properties					
pH	-	11.91	Alkaline	10.55	Alkaline
EC	dS m^{-1}	28.70	Very high	2.68	Moderate
C-organic	%	0.12	Very low	0.04	Very low
N-total	%	0.08	Very low	0.07	Very low
P-available	ppm	3.05	Very low	2.70	Very low
K_{exch}	$cmol^{(+)}$ kg^{-1}	0.76	High	0.62	High
Na_{exch} + Na_{free}	$cmol^{(+)}$ kg^{-1}	149.38	Very high	66.74	Very high
Ca_{exch}	$cmol^{(+)}$ kg^{-1}	16.98	High	21.12	Very high
Mg_{exch}	$cmol^{(+)}$ kg^{-1}	0.26	Very low	0.53	Low
CEC	$cmol^{(+)}$ kg^{-1}	25.65	High	32.56	High

* Criteria based on the standards of Indonesian Soils Research Institute (2012)

These findings are consistent with those of Thiyagarajan, Bell, Anderson, & Phillips (2011, 2012) which stated that red mud generally contained high salinity (EC 9.60 dS m^{-1}) and pH (12.00). The high values of pH and EC in the red mud was caused by the use of NaOH during the process of extracting aluminum from bauxite, during which NaOH dissolved the aluminum and formed a deposit of red mud residue with high pH and EC values. As mentioned earlier, these chemical properties of red mud make it unsuitable for use as plant growing medium. For this reason, washing treatment was tried in this study with the objective of lowering pH, EC and Na rates. Results of this washing treatment are summarized in Table 2.

In comparison, post-washing red mud showed particle size distribution of 31.2% and, 20.2% silt, and 48.6% clay; or a change in texture class into the clay. The washed red mud also exhibited reduced pH, EC, and Na (10.55, 2.68 dS m^{-1} and 66.74 $cmol^{(+)}$ kg^{-1}, respectively); nevertheless, pH and Na rates still fell under the category of very high. At the same time, both pre- and post-washing red mud sample contained still very low rates of total-N, organic-C, and available-P. Given these observations, there is a need to introduce further specific treatment in order to improve the chemical qualities of red mud and make it suitable for the requirements of an optimal plant growing medium.

Effects of Adding Ultisol Soil Material and Compost on the Chemical Properties of Red Mud Growing Medium

The effects of adding sm-Ultisol and compost into the washed red mud on its chemical properties, particularly on pH, EC, organic-C, N-total, available-P, Mgexch, Kexch, Naexch, and CEC are illustrated in Figures 1, 2, and 3, and summarized in Table 3.

Figure 1 shows that the higher the dosage of sm-Ultisol and compost that are added, the lower the pH of the red mud becomes. This result is corroborated by the outcome of the statistical test that showed that dosage of sm-Ultisol and compost, as well as their interaction, produced a significant effect on lowering the pH of the red mud-containing growing medium. Ultisol has such high acidity rate (pH 4.11) that mixing it with red mud can result in a much lower pH of the medium due to dilution by sm-Ultisol. A similar effect of lowering the pH level was also brought about by the progressive addition of compost. This can be attributed to the phenomenon in which organic acids coming from the decomposition of compost can neutralize a part of the alkalinity of the red mud growing medium. Mahdy (2011) reported a similar finding that adding 10 g kg^{-1} compost can lower soil pH, from 8.83 to 7.92.

Figure 2 shows that the addition of higher and higher amounts of sm-Ultisol resulted in progressively lower EC in the red mud-containing growing medium, while the reverse outcome was observed in the case of compost that is, as more and more compost was added, the EC of red mud-containing growing medium kept on rising. The ensuing statistical test confirmed that dosage of sm-Ultisol produces a significant effect on lowering the EC of the red mud growing medium, whereas, the addition of compost produces a significant effect in raising the EC of the red mud medium, and there was no significant interaction between the two ameliorants (Figure 2).

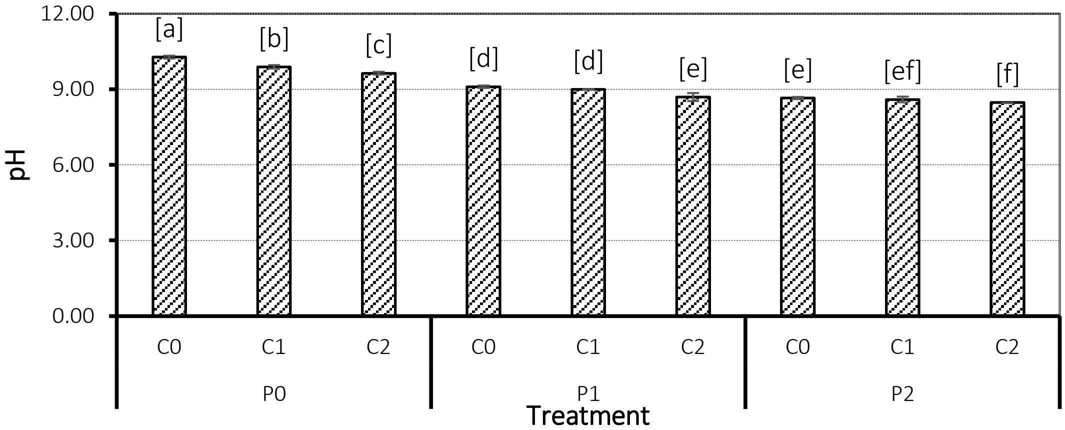

Figure 1. Effects of the addition of sm-Ultisol and compost on the pH of red mud growing medium (Similar letters in the bar graph indicate not-significant difference at 5% level of significance, using DMRT. C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag*)

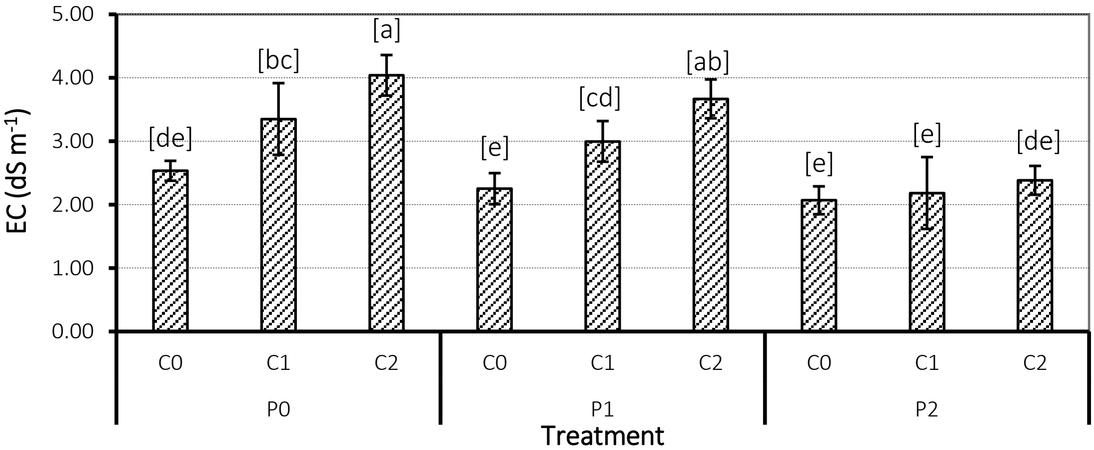

Figure 2. Effects of mixing sm-Ultisol and compost on the EC of red mud growing medium (Similar letters in the bar graph indicate not-significant difference at 5% level of significance, using DMRT. C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag)*

Table 3. Effects of mixing sm-Ultisol and compost on the nutrient element content of red mud growing medium

Treatment	C-org	N-tot	P-available	CEC	K	Mg	Ca
	----------%-----------		ppm P_2O_5	--------------------cmol$^{(+)}$ kg^{-1}--------------------			
P0C0	0.09 h	0.01 f	4.54 f	30.16 d	0.26 c	0.56 de	21.50 c
P0C1	0.53 g	0.04 e	8.13 e	31.13 d	1.11 b	0.47 e	20.05 c
P0C2	1.07 e	0.06 de	13.07 d	31.62 d	1.46 ab	0.66 d	20.08 c
P1C0	0.89 f	0.07 d	11.60 d	32.84 cd	0.37 c	0.55 de	24.91 b
P1C1	1.37 d	0.12 c	16.94 c	35.25 bc	1.26 b	0.99 c	24.48 b
P1C2	1.71 c	0.15 b	27.41 b	36.97 ab	1.84 a	1.42 b	26.36 b
P2C0	1.13 e	0.07 d	14.78 cd	36.77 ab	0.42 c	0.61 de	26.63 b
P2C1	1.87 b	0.16 ab	28.60 b	39.39 a	1.10 b	1.36 b	30.51 a
P2C2	2.14 a	0.18 a	35.26 a	39.47 a	1.80 a	1.63 a	30.40 a

Data in the Table that are followed by similar letters indicate no significant difference at 5% level of significance using DMRT. C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag*.

Ultisol soil material has a very low EC (0.06 dS m^{-1}) such that, when mixed with red mud, it can bring down the EC of the mixture as a result of the dilution of the red mud by the sm-Ultisol whereas, the addition of compost, in fact, increased the growing medium EC. This was because compost possesses high EC (11.47 dS m^{-1}), as (Jones, Haynes, & Phillips, 2010) found in their study wherein, the application of compost at a dosage of 40 t.ha^{-1} brought the EC of bauxite residue up (from 5.9 to 7.90 dS m^{-1}).

Table 3 illustrates that mixing m-Ultisol at 750 g/polybag (P2) and compost at 117.2 g/polybag (C2) can raise the level of organic-C of the red mud growing medium, from 0.09% to 2.14%, total-N from 0.01 to 0.18%, available-P from 4.54 to 35.26 ppm P_2O_5, K_{exch} from 0.26 to 1.80 cmol$^{(+)}$ kg^{-1}, Mg_{exch} from 0.56 to 1.63 cmol$^{(+)}$ kg^{-1}, Ca_{exch} from 21.50 to 30.40 cmol$^{(+)}$ kg^{-1}, and CEC from 30.16 to 39.47 cmol$^{(+)}$ kg^{-1}. The rise in the level of available-P was caused by the rise in pH of the red mud-containing growing medium since one factor that influences the availability of P is soil pH. At acidic soil reaction, the P within the soil is bound by Al and Fe ions thereby limiting its availability. Hence, as the pH of the red mud is raised, that is, made more alkaline, the P contained in the sm-Ultisol (total-P 220 ppm P_2O_5), and compost (total-P 0.76% P_2O_5) is released and becomes available to the plant roots. As a consequence, the higher the dosage of sm-Ultisol that is mixed with the red mud, and with the addition of more compost, the higher would be the level of available-P in the growing medium. This result is consistent with the finding of Jonathan W.C. Wong & Ho (1994) that as the dosage of ameliorant mixture is increased, the available-P also becomes higher. Jonathan W.C. Wong & Ho (1994) reported that the application of ameliorant gypsum and sludge at a dosage of 38.5 ton ha^{-1} and 77 ton ha^{-1}, respectively, can increase available-P from 3.8 ppm to 43.4 ppm. The level of Mg_{exch} also rose with the addition of higher amounts of sm-Ultisol and compost. This was because both ameliorants contained 1.98 and 3.81 cmol$^{(+)}$ kg^{-1} of Mg_{exch}, respectively, such that they could raise the level of Mg_{exch} of the red mud growing medium by as much as 1.63 cmol$^{(+)}$ kg^{-1}. The same trend was observed in the case of K_{exch} as the compost contained a very high amount of K_{exch} (57.16 cmol$^{(+)}$ kg^{-1}). A similar significant effect was likewise observed on Ca_{exch} of the red mud growing medium with the addition of sm-Ultisol, as a result of dilution of Na_{exch} (Figure 3) in the red mud thereby, causing the proportion of Ca_{exch} to likewise rise.

Figure 3 shows that the higher proportion of sm-Ultisol is added to the red mud, the lower would be the rate of Na_{exch} in the mixture. This is because sm-Ultisol contains very low Na_{exch} thereby, resulting in the dilution of the Na_{exch} element in the red mud. The reduction in Na_{exch} also contributes to the reduction of the EC of the red mud growing medium (Figure 2).

Effects of Adding Ultisol Soil Material and Compost on the Level of Nutrient Elements in the Leaves of Sengon Plant

The effects of mixing sm-Ultisol soil and compost on the levels of macro-nutrient elements N, P, K, Ca and Mg in the leaves of the experimental sengon plant are summarized in Table 4, while Table 5 shows the observed effects on the levels of micro-elements Fe, Cu, Zn, and Mn.

As can be seen in Table 4, there was no observed significant difference caused by all treatments on the levels of N, P, K, Ca and Mg in the sengon plant leaves. The levels of macro-elements in the sengon leaves at all treatments did not show any significant difference. All these data of the levels of N, P, K, Ca and Mg in the sengon plant leaves indicate that the availability level of macro-nutrients is not the main inhibiting factor of the sengon growth on the treatments.

It is noteworthy that Treatment P0 (No sm-Ultisol added) could not be analyzed anymore because the experimental sengon plants died within 3-8 WAP. Very likely, the young sengon plants died at this Treatment P0, either mixed with compost or not, because pH and Na_{exch} levels were too high. The presence of excessive total amounts of Na^+ ions caused the experimental plants to undergo plasmolysis, or the movement of moisture out of the plant cells into the soil solution, eventually resulting in permanent wilting of the plant (Tan, 2011).

The effects of adding sm-Ultisol and compost to red mud on the levels of micro-nutrient elements (Fe, Cu, Zn, and Mn) in the leaves of experimental sengon plants are shown in Table 5. The optimum limit for Mn in plants is 300-500 ppm, and for Zn, it is 25-150 ppm, according to Suchartgul, Maneepong, & Issarakrisila (2012) and Munawar (2011). Again, this outcome implies that substantial supplemental amounts of the micro-nutrient elements Fe, Mn, and Zn still need to be applied to the red mud in order to gain optimal benefits for plants.

The levels of Cu in the experimental sengon plant leaves, at all treatments, did not show any significant difference. The low levels of micro-nutrient elements in the sengon plant leaves were brought about by the very high pH in the red mud growing medium (Figure 1), such that the micro-nutrient elements become sparingly soluble thereby, lowering their available levels and hence limiting absorption by plant roots. This finding is consistent with those of Barrow (1982); Reuter & Alston (1975); Santona, Castaldi, & Melis (2006) that mobility in the micro-nutrient elements, such as Mn and Zn, is quite low in soils of high pH. Furthermore, the levels of micro-nutrients Mn and Zn in bauxite residues are in the form of non-available and very limited (Anderson, Bell, & Phillips, 2011; R. Courtney, Timpson, & Grennan, 2003; Fuller & Richardson, 1986; Gherardi & Rengel, 2001; Thiyagarajan, Phillips, Dell, & Bell, 2009).

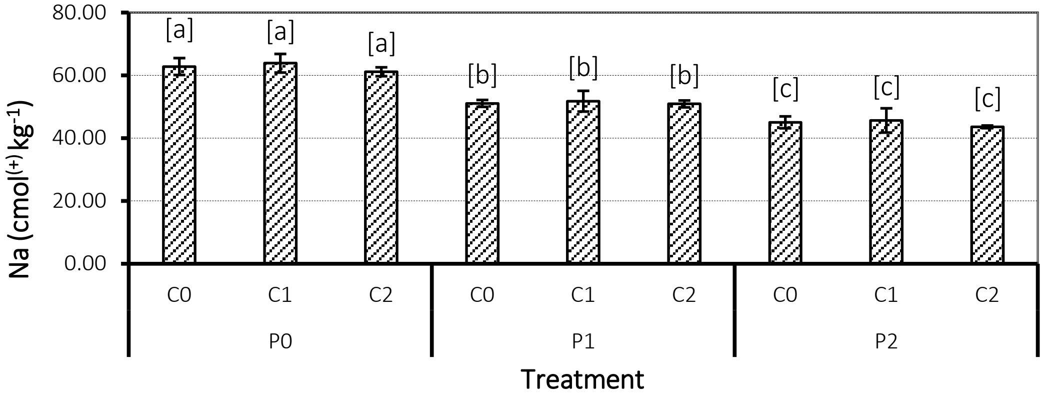

Figure 3. Effects of the addition of sm-Ultisol and compost on the rate of Na of the red mud growing medium (Similar letters in the bar graph indicate not-significant difference at 5% level of significance, using DMRT. C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag)*

Table 4. Effects of adding sm-Ultisol and compost into red mud growing medium on the macro-nutrient elements in the sengon plant leaves

Treatment	N	P	K	Ca	Mg
	----------------------------------%----------------------------------				
P0C0	-	-	-	-	-
P0C1	-	-	-	-	-
P0C2	-	-	-	-	-
P1C0	2.70	0.23	1.65	0.39	0.29
P1C1	3.02	0.22	2.42	0.36	0.20
P1C2	2.88	0.21	2.02	0.42	0.19
P2C0	3.30	0.19	1.37	0.44	0.22
P2C1	3.08	0.18	2.08	0.52	0.24
P2C2	2.66	0.22	2.17	0.47	0.27

C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = Proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag*. (-) No analysis was done since all experimental sengon plants died.

Table 5. Effects of adding sm-Ultisol and compost into red mud growing medium on levels of micro-nutrient elements in the leaves of experimental sengon plants

Treatment	Fe	Cu	Zn	Mn
	------------------------------ppm--------------------------------			
P0C0	-	-	-	-
P0C1	-	-	-	-
P0C2	-	-	-	-
P1C0	229.5	6.4	20.6	55.3
P1C1	244.2	6.1	19.8	67.8
P1C2	244.3	5.8	18.9	65.1
P2C0	200.5	5.9	20.8	72.7
P2C1	233.7	6.3	16.8	87.8
P2C2	238.1	6.9	26.5	134.4

C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = Proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag*. (-) No analysis was done since all experimental sengon plants died.

Table 6. Effects of adding sm-Ultisol and compost into the red mud growing medium on the growth of experimental sengon plants, at 12 WAP

Treatment	Height Increment	Diameter Increment	Root Length	Plant Dry Weight
	------------------------- cm	-------------------------		g
P0C0	-	-	-	-
P0C1	-	-	-	-
P0C2	-	-	-	-
P1C0	2.00	0.08	11.5	3.54
P1C1	3.67	0.09	10.3	3.69
P1C2	3.87	0.13	17.1	3.94
P2C0	4.93	0.16	20.7	6.42
P2C1	9.43	0.19	20.5	10.68
P2C2	13.67	0.30	32.7	17.68

C0, C1, C2 = Compost at dosage 0; 2.5; 5 kg/planting hole. P0, P1, P2 = Proportion of mixture red mud with sm-Ultisol at 1500+0, 1000+500, 750+750 g/*polybag*. (-) experimental sengon plants died at 3-8 WAP

Effects of Adding Ultisol Soil Material and Compost on the Growth of Sengon Plants

Table 6 shows the effects of adding sm-Ultisol and compost into the red mud growing medium on the growth of experimental sengon plants, particularly in terms of plant height, stem diameter, root length, and dry weight, after 12 WAP.

At Treatment P0 (without the addition of sm-Ultisol), the sengon plants survived only for about 3-8 weeks after planting (WAP), largely because the red mud medium had too high pH and Na_{exch} content, that caused plasmolysis in the plants. As indicated in Table 6, higher dosage levels of sm-Ultisol and compost that were mixed with the red mud boosted progressively the growth of the planted sengon.

The best treatment in this study was that is, P2C2 with 1:1 sm-Ultisol and red mud ratio, and adding 117.2 g/polybag of compost. This conforms to the changes in the properties of the red mud-containing growing medium which is much better at Treatment P2C2, as reflected by the pH, EC, organic-C, total-N, available-P, Mg_{exch}, $Ca_{exch,}$ and CEC, and as depicted in Figures 1, 2 and 3 in conjunction with Table 3. Given this condition of the red mud growing medium, best plant growth can be expected, as exemplified by height increment of 13.67 cm, stem diameter growth of 0.30 cm, root length of 32.7 cm, and dry weight of the plant of 17.68 g.

CONCLUSION

This study has established that: (1) Washing of red mud can reduce its pH, EC, Na_{exch} levels, from 11.91, 28.70 dS m^{-1}, and 149.38 $cmol^{(+)}$ kg^{-1} to as low as 10.55, 2.68 dS m^{-1}, 66.74 $cmol^{(+)}$ kg^{-1}, respectively; (2) Mixing the red mud with Ultisol soil material at 1:1 ratio is effective in lowering the levels of pH, EC, and Na_{exch} from 10.28, 2.53 dS m^{-1}, and 62.79 $cmol^{(+)}$ kg^{-1} to 8.65, 2.07 dS m^{-1}, and 45.01 $cmol^{(+)}$ kg^{-1} of the mixture respectively as a result of dilution; (3) Adding 117.18 g of compost per polybag can reduce pH from 10.28 to 9.64, and can raise the level of organic-C from 0.09 to 1.07%, total-N from 0.01 to 0.06%, available-P from 4.54 to 13.07 ppm P_2O_5, K_{exch} from 0.26 to 1.46 $cmol^{(+)}$ kg^{-1}, Mg_{exch} from 0.56 to 0.66 $cmol^{(+)}$ kg^{-1}, and CEC from 30.16 to 31.62 $cmol^{(+)}$ kg^{-1} of red mud containing growing medium (4) Within the scope of this study, the best treatment combination in terms of greatest plant growth is treatment of 1:1 mixture of red mud and Ultisol soil material with the addition of 117.18 g of compost per polybag that can produce plant height increment 2.00 to 13.67 cm, stem diameter growth from 0.08 to 0.30 cm, root length from 11.50 to 32.70 cm, and dry plant weight from 3.54 to 17.68 g.

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